High Speed Optical Transmitter and Receiver Development for Lidar and Communications

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LONG-TERM GOAL

My long-term goal concerns component development for a novel hybrid lidar-radar system for underwater surveillance. Preliminary ocean experiments of the hybrid lidar-radar system have confirmed the potential of microwave-modulated pulsed lidar to be a superior detection mechanism for underwater surveillance [1]. The next step in the evolution of this novel technique is the improvement of the key components of the measurement system: high speed, large area photodetectors and microwave modulated pulsed laser sources.

OBJECTIVES

I have two specific objectives in this project. The first is the design, fabrication and testing of an advanced optical transmitter for lidar-radar and communications. The optical transmitter can generate a low phase and intensity noise optical carrier with a rapidly tunable millimeter wave sub-carriers.

The second objective concerns the development of an optical phased array receiver for the hybrid lidar-radar system. Both the conventional lidar systems and the hybrid lidar-radar systems utilize amplitude detection for target acquisition and ranging. My goal with the optical phased array receiver is to explore the use of the phase content of the microwave return signal to give information about the direction of the return optical signal and the physical properties of the target.

APPROACH

Since we are reporting on two separate components for the hybrid lidar-radar system, the approach of the optical transmitter will be discussed first, followed by the phased array receiver.

Optical Transmitter

The optical transmitter is based on tunable, microchip laser technology. The basic microchip laser configuration is depicted in Figure1, where a single Neodymium (Nd) doped Lithium Niobate ($LiNbO_3$) slab contains two identical lasers mounted on a single substrate.

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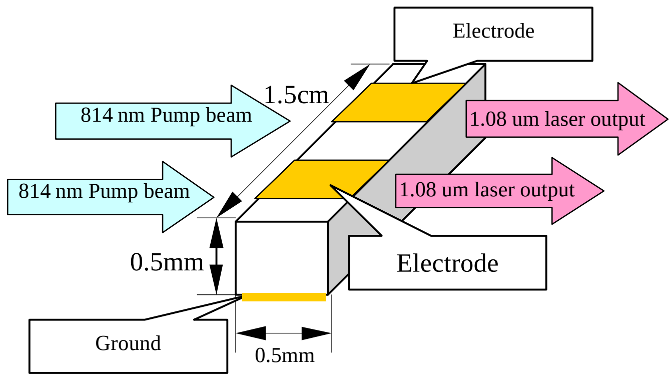


Figure 1. Microchip Laser Configuration

The optical cavity is formed by dielectric mirrors, which are deposited directly on the host crystal. The identical devices are pumped by semiconductor laser arrays. The length of the optical cavities is set to 0.5mm, which ensures both single-mode operation of the lasers and high pump absorption efficiency. Gold electrodes are deposited on the top and the bottom of the lasers in the transverse direction. Ideally, in the absence of an applied electric field, the two lasers emit at identical wavelengths of 1.084 μm (small differences in the optical output frequencies can be compensated for by a small DC bias). However, by applying an electric field via the gold electrodes of one of the lasers, the index of refraction is modulated. This produces a shift of the output wavelength and sets the stage for heterodyning to produce a tunable millimeter wave signal.

The gain-bandwidth of a Nd doped $LiNbO_3$ was determined to be 120 GHz [2], which represents the upper bound of the tuning range. The monolithic configuration gives the system simplicity, compactness, stability, and insensitivity to external temperature fluctuations. It should be pointed out that the only electrical inputs are for tuning. A device thickness of d=0.5mm yields a tuning sensitivity of 40MHz per volt, which results in a practical tuning range of up to 50GHz. We estimate that the thickness of the slab can be halfed, which of course would double the tuning range. It should be noted that the short cavity length prevents mode hopping.

To minimize the noise of the heterodyned beat signal, an optical phase locked loop and optical injection locking scheme has been explored. Since the output of the microchip laser has an extremely narrow linewidth (~ several kilohertz), the phase lock loop alone would ensure sufficiently low noise performance for most applications [2]. For applications that require extremely low noise characteristics and large tunability, such as a frequency hopped secure communication system, optical injection locking needs to be added.

Optical phased array receiver

In the hybrid lidar-radar phased array detection scheme, an underwater target is illuminated by a blue-green light beam and the echo is detected by an array of high speed photodetectors. The optical beam is scattered randomly and dispersed in the water, and the return signal is incoherent in the optical domain. However, in the microwave domain the target produces a coherent reflection with a specific wave front that is accompanied by the random backscatter from the particulate in the water, which constitutes a clutter. In addition to the clutter, the return signal contains multi-path interference due to this random scattering. In principle, the microwave phase differences measured by the array should relate to the angle of inclination of the return wave front, which can be used to determine the location and the shape of the target.

To prove the concept, the study has been divided in three experimental steps.

- The first step is to simulate the return signal wave front in the absence of clutter and multi-path interference. This step has been completed and the results are presented below.
- The second step would be to simulate the return wave front with clutter but in the absence of multi-path interference. This experiment is in progress.
- The third step would be to simulate the return wave front from the target in presence of clutter and multi-path scatter and will be conducted upon completion of step two.

The experimental setup for emulating the return wave front of an underwater measurement in the absence of clutter and multi-path interference (step one) is shown in Figure 2.

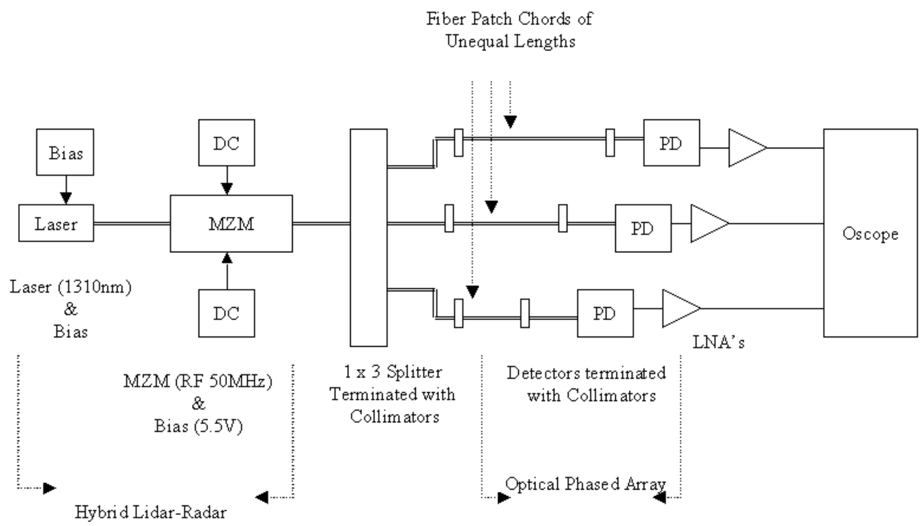
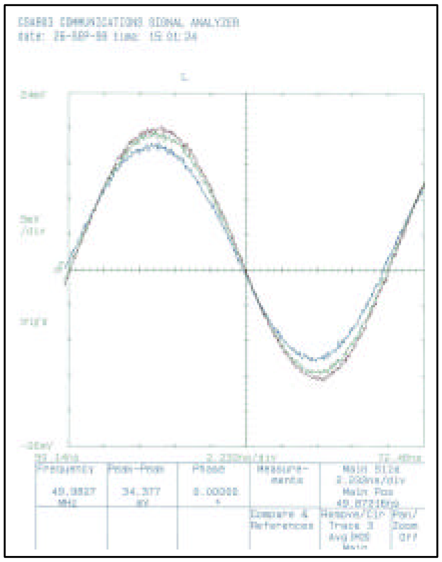


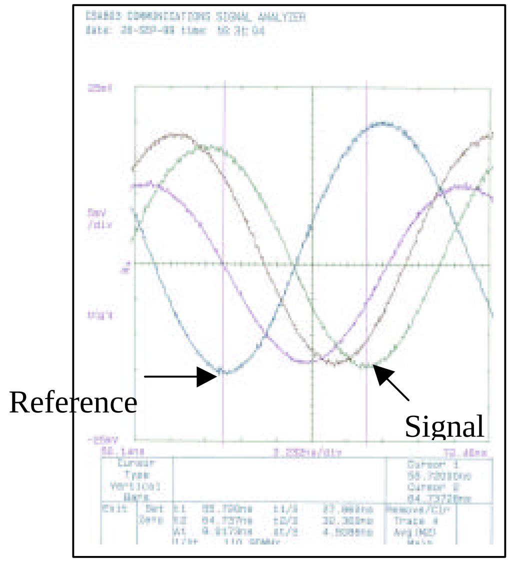
Figure 2. Hybrid Lidar-Radar Phased Array Experimental Setup

The return signal at various points in the reflection beam are simulated using three optical sources generated by splitting the output of an intensity modulated laser. The phased array of photodetectors at the receiver detect the microwave wave front, which is subsequently amplified using low noise amplifiers to view the return signals on an oscilloscope. A phase difference between the output signals is created by unequal propagation path lengths of each intensity-modulated signal. The objective of our experiments is to ensure that we are able to detect and compare these phase differences. Fiber patch cords of various lengths are connected between each splitter output and photodetector, simulating the free space propagation of unequal distances in the absence of clutter and multi-path interference.

A calibration measurement is performed at an RF modulation frequency of 50 MHz where all the path lengths are equal and hence all the three detected signals are in phase. The three in-phase output signals are shown in Figure 3a and serve as reference for all following measurements. With the three different length fiber patch cords inserted before the photodetectors, the time delay between the reference and each output signal can be measured using the oscilloscope, as shown in Figure 3b, and used to calculate the phase difference.



(3a)



(3b)

Figure 3. In Phase Measurement (3a) and Difference Measurement (3b)

Excellent agreement between the theoretical and calculated phase shifts has been achieved as summarized in Table 1.

Table 1. Theoretical and Measured Phase Difference Results

Path Length (m)	Δt (ns)	Calculated Phase Difference (deg)	Observed Phase Difference (deg)
1.8	9.017	162	162.3
1.42	7.097	127.8	127.7
1.09	5.312	98.1	95.6

Having established the feasibility and accuracy of the hybrid lidar-radar phased array scheme, follow on experiments are planned to further explore the phase integrity of the RF signal in cluttered and multi-path interference scenarios.

RESULTS

A tunable high-speed optical transmitter has been designed an analyzed. The transmitter consist of two microchip laser co-located on the same Nd doped $LiNbO_3$ crystal. The output of the two lasers are heterodyned to produce a tunable millimeter wave signal. The ultras-short cavity design provides for single mode operation with superior optical spectrum quality, while maintaining good pump efficiency.

The monolithic configuration of realizing two lasers within one microchip crystal makes the transmitter more tolerant to the environmental fluctuations. Several schemes of the phase stabilization have been investigated. The tuning sensitivity is 40MHz /volt and continues tuning range is 50GHz.

A hybrid lidar-radar phased array scheme has been devised which can provide information regarding the angle of arrival and shape of the underwater target by sampling the return RF/microwave signal wave front. A three step experimental approach has been adopted to evaluate this scheme by first measuring the microwave envelope phase integrity in the absence of background clutter and multi-path interference environment, followed by a cluttered but multi-path interference free scenario, and lastly in the presence of both clutter and multi-path interference. The first measurement environment was emulated by launching an RF intensity modulated optical signal in various lengths of optical fiber and measuring the resultant phase differences. Excellent agreement between theoretical and measured results was achieved, thus proving the feasibility of the scheme.

IMPACT/APPLICATION

With the approach we have taken for the development of the optical transmitter, we see several applications. These include frequency chirped lidar-radar system, optical/wireless communications for picocellular telephony and wireless local area networks (WLAN), transmission of millimeter waves over optical fiber, and biomedical imaging. These applications all require optical transmitters that can generate rapidly tunable, low phase noise and low intensity noise millimeter wave sub-carriers.

The hybrid lidar-radar phased array scheme shows tremendous potential for detection and imaging in highly scattering environments. With the ability to preserve the integrity of the microwave envelope after the optical carrier is no longer coherent, detection of targets can be accomplished in applications where the integrity of the optical signal has limited the use. With some modifications, this scheme can also be applied to the localization of hidden absorbers in a dispersive medium [3], and for detection of tumors, aneurysms or hemorrhages in human brains, breasts or muscles.

TRANSITIONS

There have been no transitions to other programs to date.

RELATED PROJECTS

There are no related projects to date.

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